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Atmospheric Measurement Techniques Discussions

Interactive comment on "Radio occultation bending angle anomalies during tropical cyclones" *by* R. Biondi et al.

R. Biondi et al.

ribi@space.dtu.dk

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Radio occultation bending angle anomalies during tropical cyclones by Biondi et al. This is a very interesting idea, but some the results presented require further clarification before publication. If the following points can be addressed, the paper should be published.

Comment: Page 1372: line 23, GPS radio occultation measurements are unlikely to provide much useful information on UTLS water vapour. This should be clearer in the text.

Reply: We have changed the last sentence of the introduction as: "Although GPS RO observations are not sensitive to the small amounts of water vapor in the UTLS, the

bending angle and the temperature profiles show a clear signature of the convection in the UTLS which is confirmed by the comparison with co-located radiosonde (RAOB) data"

Comment: Section 3, page 1376 line 5. Discussion of the CDAAC 1D-Var. A description of the CDAAC 1D-Var background and observation error model is required. In particular, (with relevance to Figure 11) what are the assumed background humidity errors in the stratosphere? The sentence " derived temperature (T), pressure (P), and water vapour (e) are basically consistent with the observed refractivity (N)..." is too simplistic. All 1D-Var calculation attempt to find a solution that is consistent with the refractivity observations, given the assumed refractivity errors. I believe the CDAAC approach is to assume smaller errors than are generally justified by error propagation studies. Please revise this section.

Reply: As far as we know, the CDAAC approach is to apply virtually no weighting to the background profile, or equivalently assume that the error of the refractivity observation is virtually zero. This was done at CDAAC some years ago to ensure that the solution of p, T, and e is consistent with the observed refractivity via the refractivity equation. In practice, in the processing system at CDAAC, the weight given to the background is non-zero, but small enough such that the above is ensured to a very high degree. Thus, there is very little difference between, e.g., the 1Dvar solution of temperature and the corresponding retrieved dry temperature in regions where moisture is insignificant. Temperature differences may appear at higher altitudes, which we don't quite understand (we do not have full knowledge of the computational details of the CDAAC 1Dvar approach), but these altitudes are not discussed in the paper. One example generated with the tools at the CDAAC website is shown in figure 1.

The red curve is the dry temperature; the black is the 1Dvar solution; the green is the profile extracted from low resolution ECMWF fields used in the 1Dvar approach. In the paper we will add the following after eq. (1):

“Thus, the physical relation between the solution and the observed refractivity is preserved, and the temperature is basically the same as the so-called dry temperature in regions where moisture is insignificant. The approach still includes information from ECMWF fields to separate out the meteorological variables in the moist troposphere, but it seeks to minimize the influence from the ECMWF fields and it preserves the full information coming from the observations.”

Comment: Page 1378, last paragraph. Is it surprising that the double spike can be observed in the bending angles, but a double tropopause is not evident in the temperature retrieval, given that the temperature retrievals are expected to be quite accurate here? Can you be sure a double spike implies a double tropopuase? Could it be a spherical symmetry issue?

Reply: Almost 97% of the cases where we get the double spike in the bending angle anomaly also show the double tropopause. This is statistically relevant. The figure 2 shows the temperature anomaly and the bending angle anomaly (averaged values for all the cases) from GPS ROs, 5 km below and above the reference Zo which is the altitude of the warming between the two tropopauses. Five km below Zo, the troposphere is warmer than the climatology and the bending angle anomaly is negative. The first tropopause (lowest coldest point) corresponds to the lower spike of the bending angle and above the warming there is a new decrease of the temperature corresponding to the bending angle increase. The amplitude of the highest coldest point (and bending angle spike) is not so large as the lower one, since the second tropopause does not occur always at the same vertical distance from the warming, so the average, smoothes it. We added this plot to the paper together with the description.

We also report here some additional examples (one of them also added to the paper) in figure 3 and figure 4: in green the bending angle anomaly vs altitude in red the corresponding temperature profile from GPS RO and in blue the temperature profile from RAOB .

Comment: Figure 2: This doesn’t seem to add much to the paper.

Reply: The figure 5 shows how ACES will contribute to increase the number of radio occultation in the tropical areas. To provide a better idea of the ACES contribution, we increased the resolution of the figure (from 2 latitudinal degrees to 1) and we changed the Fig. 1 of the manuscript (figure 6 of this document) to be easier comparable with the ACES coverage. Within 15S and 15N the mean number of COSMIC ROs per month per latitudinal degree is 208. ACES will increase this number with additional 65 events which means about 32% more. In the paper we added the sentence: “The inclination of ISS orbit (51.6) will allow the ACES GPS receiver to monitor the major convective regions of the Earth contributing to increase the number of GPS RO within the tropical regions by 32%”

Comment: Figure 3: Can the authors provide any explanation for the shape of the bending angle anomaly, in terms of typical TC characteristics (eg, surface pressure, water vapour).

Reply: The following sentence will be added to the paper: “3 distinct regions are clearly recognizable, each with different trends: the lower troposphere, the mid/upper troposphere and the UTLS. In the lower troposphere there is an increase of the bending angle anomaly due to the combined effect of the increase of water vapor (which prevails) pushed up by the convection and the warming due to the instability of the TC. Moving to higher altitudes, the water vapor content decreases and the contribution of the temperature variation prevails. We have not deepened the study of the negative bending angle anomaly just below the top of the TC (between 10 km and 14 km of altitude in the figure). Finally, the increase of the bending angle anomaly in the UTLS, is completely due to the temperature variation since the water vapor content amount is usually extremely low.”

Comment: Figure 9: The RO retrieval differs from the radiosonde by _5K at 20 km. This seems to be a very large difference which requires some explanation.

Reply: This difference is probably due to the coarse vertical resolution of the RAOB and to the distance between the RAOB and the GPS RO (about 98 km). The RAOB temperature profile converges to the GPS RO profile just above 20 km. The figure 7 shows the comparison between the 2 temperature profiles form the ground to 22 km of altitude.

Comment: Figure 10: It is surprising that the temperature and bending angle anomalies are so similar given that the bending angles are related to the density gradients in the stratosphere, and this will have a 1/T dependence. Please explain.

Reply: It is correct that there should be a 1/T dependence between the bending angle anomaly and the temperature anomaly. In figure 10 was reported the reverse temperature anomaly (climatology-TC profile) to show the same behavior, but this was not explained in the caption. Since the information of the temperature anomaly profile is also included in the temperature profile showed in figure 9, we decide to plot the bending angle anomaly together with the temperatures as in figure 8 of this document.

Comment: Figure 11: I am very sceptical about the value of the “RO” water vapour profile shown in this figure. I suspect that it is almost entirely provided by the of the ECMWF background used in the 1D-Var. Please investigate the differences between the water vapour retrieval and the ECMWF background.

Reply: It is correct that the water vapor profile is highly influenced by the ECMWF model, in particular in the UTLS (and above) where the water vapor term (second term on the right-hand-side of eq. 1) contributes very little to the total refractivity. This is now clarified in the text. We show in figure 9 the comparison with the water vapor mixing ratio from ECMWF model. We decided anyway to remove this figure from the paper since we are evaluating the reliability of the RAOBs at this altitudes.

Interactive comment on Atmos. Meas. Tech. Discuss., 4, 1371, 2011.

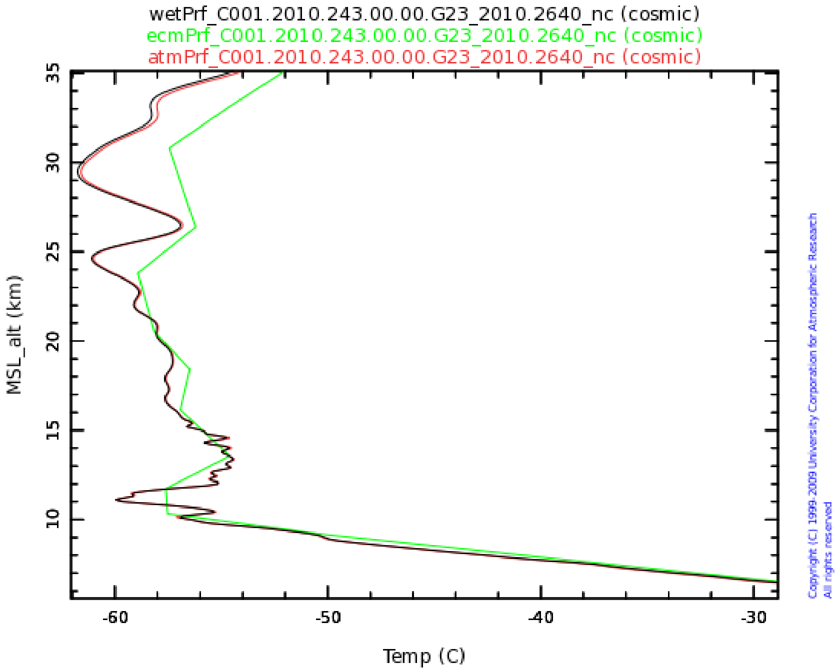

Fig. 1. Temperature profile comparison from different products.

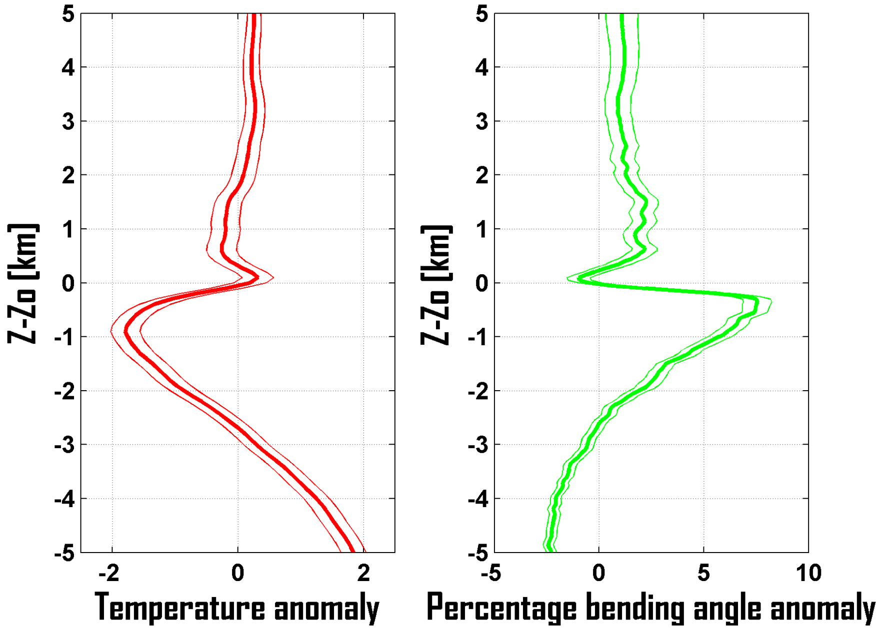

Fig. 2. The averaged temperature anomaly and bending angle anomaly profiles in bold (together with the standard deviation of the mean) 5 km below and above the warming altitude (Zo) between the 2 tropopauses.

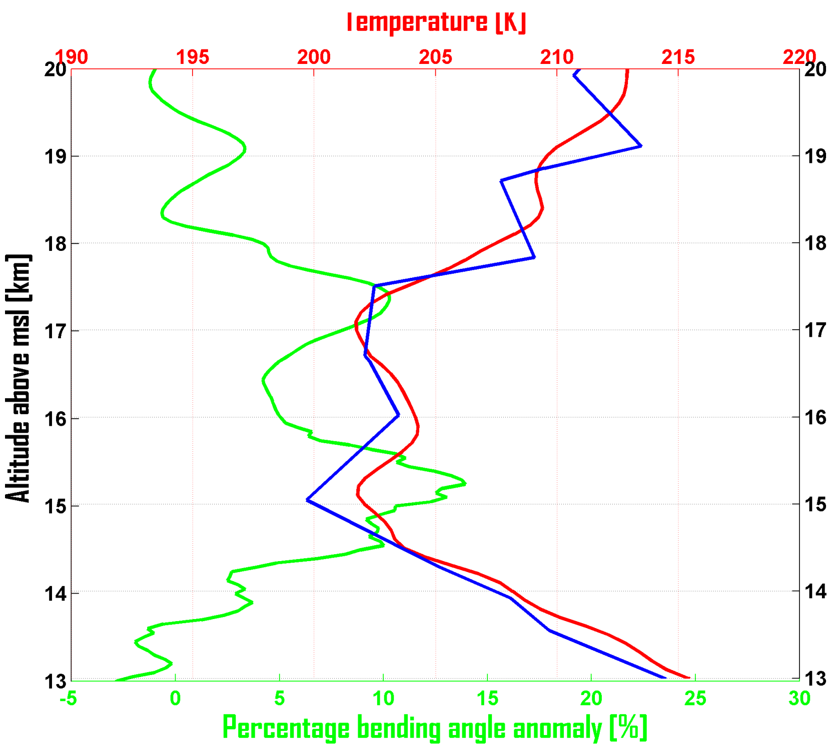

Fig. 3. Bending angle anomaly (green) and temperature (red from GPS RO and blue from RAOB) profiles during tropical cyclone.

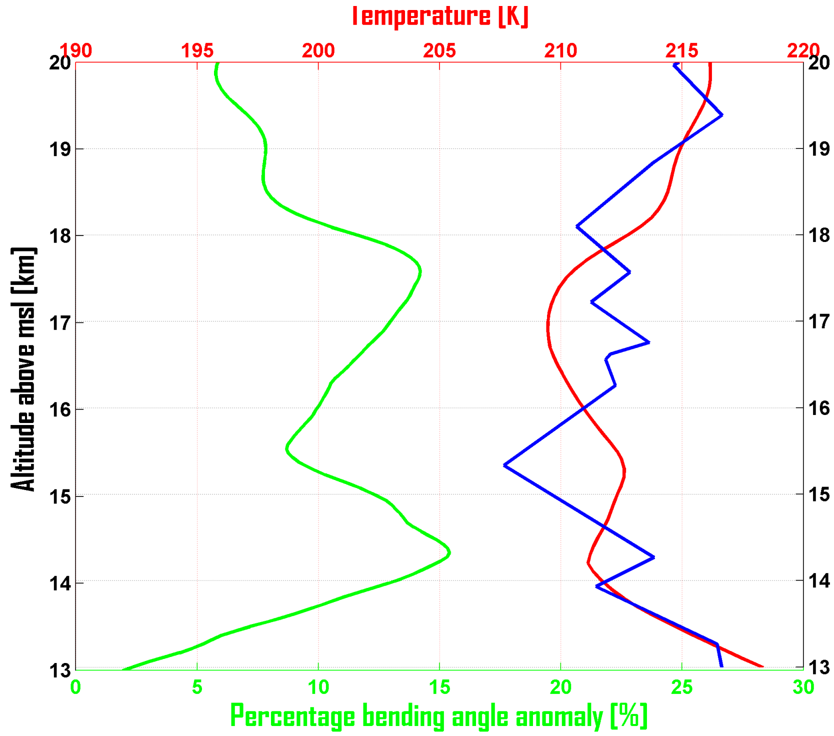

Fig. 4. Bending angle anomaly (green) and temperature (red from GPS RO and blue from RAOB) profiles during tropical cyclone.

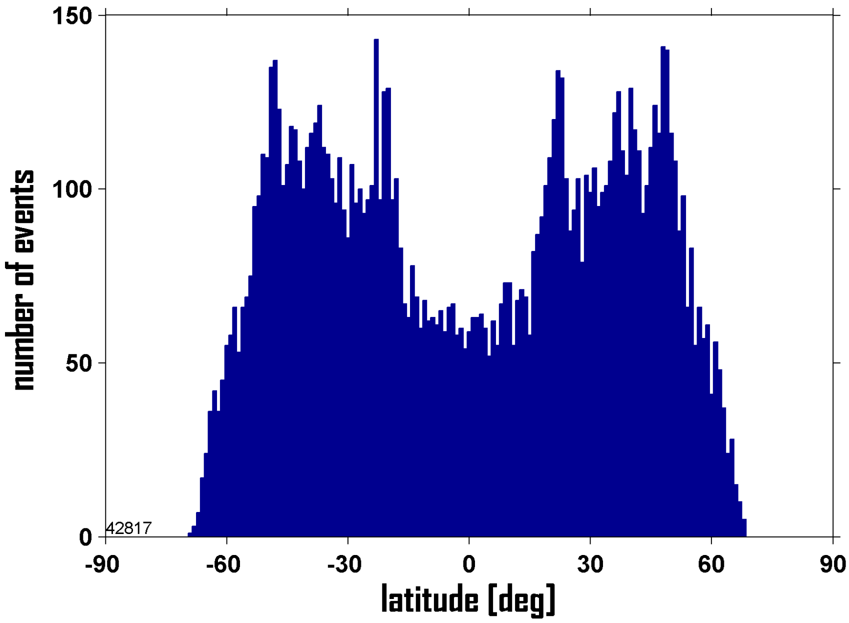

Fig. 5. ACES radio occultation coverage. Simulated monthly latitudinal distribution of ACES occultations.

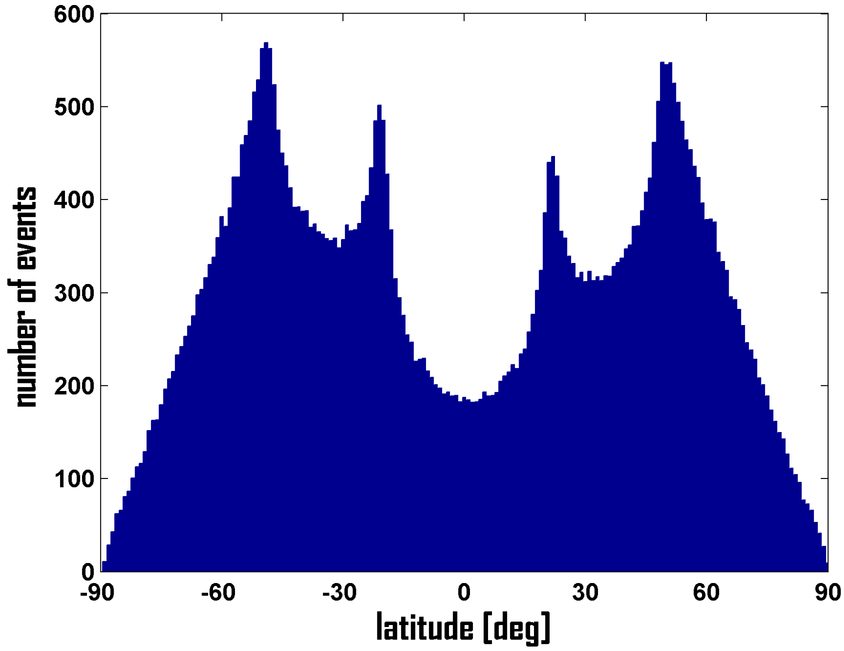

Fig. 6. COSMIC radio occultation coverage. Monthly latitudinal distribution of COSMIC occultations.

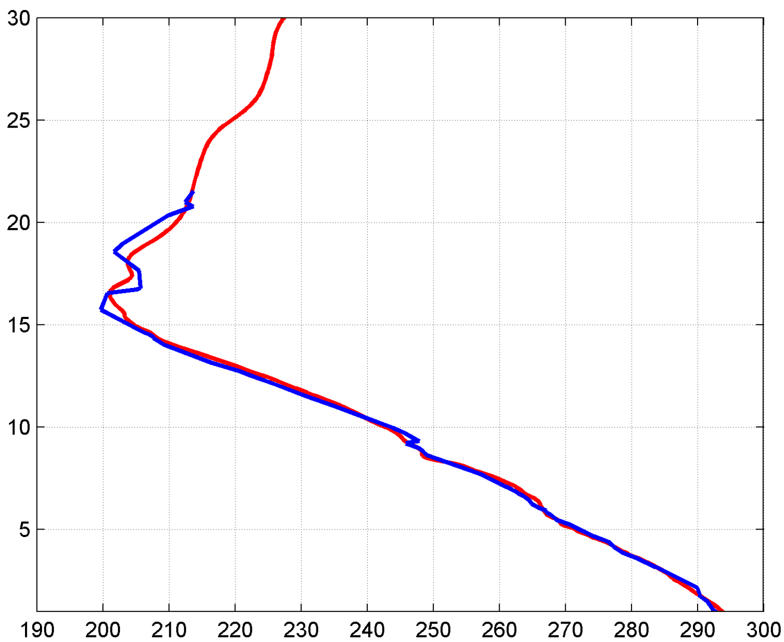

Fig. 7. Temperature profile comparison between the GPS RO (red) and the RAOB (blue) versus altitude.

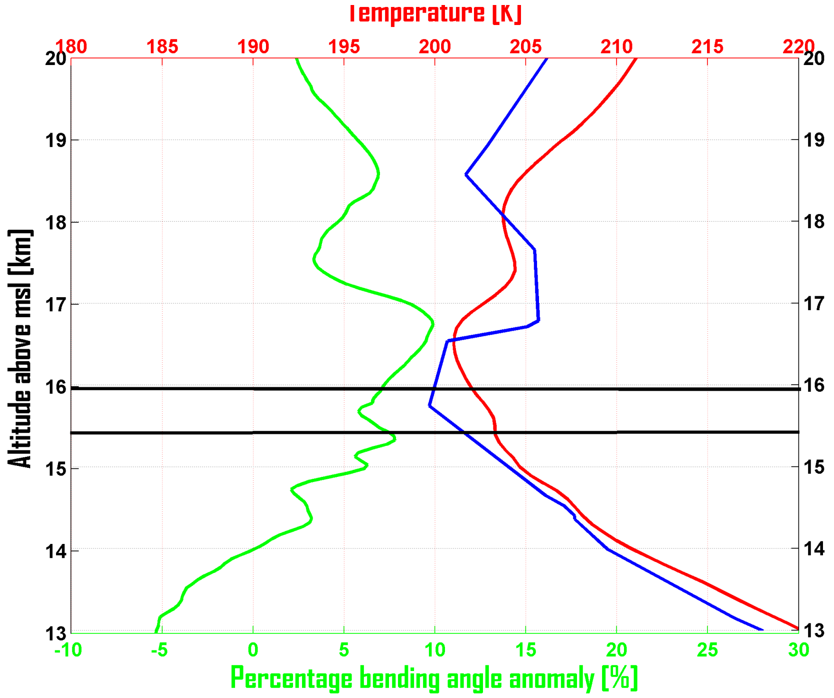

Fig. 8. Event Bertha 12 July 2008, 12:47:00 UTC: Bending angle percentage anomaly (green) and corresponding temperature profile from RAOB (blue) and from RO (red), between 13 and 20 km.

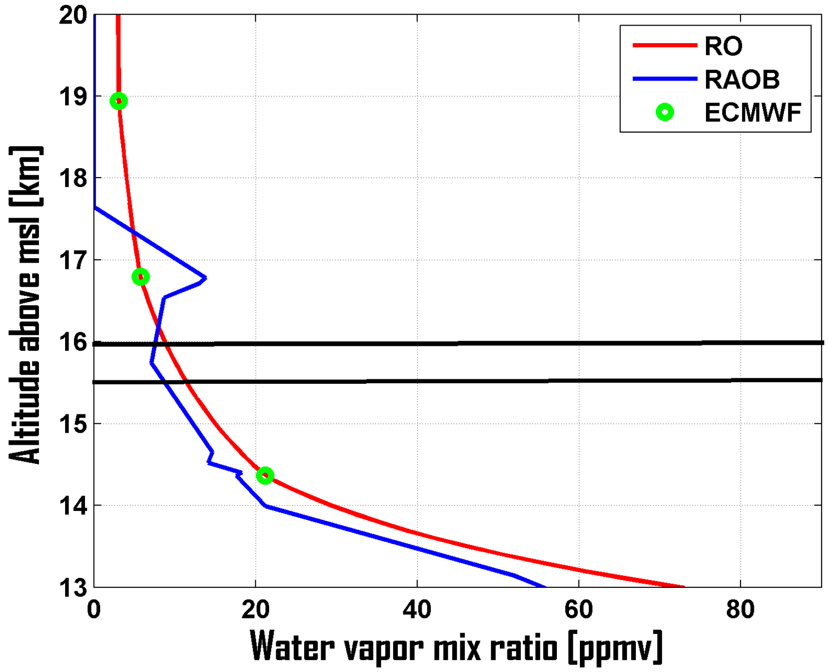

Fig. 9. Water vapour mixing ratio from the RAOB (blue), the RO/1DVar (red), and the ECMWF model (green) between 13 and 20 km.